Delete the following text from page 1:

--Statement Regarding Federally sponsored R&D
Not applicable

Reference to Microfiche Appendix
Not applicable --

Amend the paragraph under the heading "Field of the invention" on page 1 to read as follows:

a2

The invention pertains to optical communications and in particular to the control of optical beams using adaptive optical elements.

Amend the first full paragraph on page 2 to read as follows:

a3

The field of communications has benefited enormously from the introduction of optical communications technology. Fundamentally, this technology exploits the inherent bandwidth potential of the light itself as a carrier for communications signals. As this technology matures, the need for the direct optical processing of the signals is becoming greater. Much of the communications infrastructure in operation in the field today relies on signals being converted from optical form back to electrical form for much of the signal processing and management. Direct optical processing has the benefit of avoiding the need for optical to electrical and electrical to optical conversion equipment with its associated costs, losses, and amplification requirements.

Amend the second full paragraph on page 2 to read as follows:

a4

One of the critical issues within the field of optical communications relates to the situation where many optical signal channels on parallel fibers have to be

a4 cont

controlled, adjusted, or switched at a single point in the communication system. This issue creates a corresponding need for a microelectronic device with a considerable level of device integration and individually adjustable channels. Simultaneously there is a clear need for devices that will perform these functions while being rapidly adjustable in operation. It is also desirable for candidate devices to have relatively low insertion losses and a minimum possible wavelength dependence.

Amend the third full paragraph on page ~~3~~ to read as follows:

a5

One of the fundamental building blocks of an optical communications system is the optical cross-connect or optical crossbar switch. Optical crossbar switches function to selectably connect any one of an array of incoming optical signals to any one of an array of outgoing channels. Inherently these devices consist of a multiplicity of optical communications channels which may be implemented on a semiconductor wafer using micro-machining technology.

Amend the first full paragraph on page 3 to read as follows:

a6

A variety of specific individual device structures have been proposed and fabricated to address the above-described application. Many of these devices rely on non-linear optic materials to obtain switching actions. Another popular way to address the above described application is by means of micro-electromechanical structures. These micro-electromechanical structures are usually micro-mirror devices that tilt, flex, or flip upon application of an appropriate control voltage.

Amend the third full paragraph on page 3 to read as follows:

a7

The small apertures involved in the light-carrying cores of the optical fibers, particularly single mode fibers, lead to considerable beam divergence. Divergence is typically addressed by using suitably small micro-lenses that seek to collimate or focus the divergent light beam emerging from the input signal optical fiber. At the output end of a crossbar switch there is a corresponding requirement for a lens to ensure appropriate coupling of the optical beam to the output optical fiber. Again, there are great constraints on the scope of the physical dimensions of these devices.

Amend the paragraph spanning pages 3 and 4 to read as follows:

a8

A particular problem in these arrangements is the fixed nature of the micro-lenses which restricts the latitude of design available to optical engineers. It also puts constraints on the silicon micro-machined optical switching devices that typically form the heart of these crossbar switches, in that the optical switching devices have to be fabricated such that they are optically matched to the fixed lenses in order to ensure minimum insertion losses and to restrict losses inside the devices.

Amend the first full paragraph on page 4 to read as follows:

a9

These design restrictions would be reduced if suitable adaptive micro-lenses were available. Since one of the strengths of optical communications is the very wide bandwidth that it makes possible, there is every incentive to ensure that the optical devices and elements that are part of optical crossbar switches are commensurately fast, as this determines the rate at which routing and managed networking of the communication signals may be achieved. This issue applies not only to

a9 cont'd

the sophisticated silicon devices in a crossbar switch, but also to any adaptive micro-lenses within such a crossbar switch.

Amend the second full paragraph on page 4 to read as follows:

a10

Liquid crystal lenses to address some of these issues are known in the art. However, these devices have limited speed due to the inherently slow switching speed of the liquid crystal mechanism. Over the past decade, much collective effort was devoted to deformable macroscopic mirror devices for light projection systems, and in this respect piezoelectrically deformed lenses are known, but these clearly do not lend themselves to application in miniaturized optical crossbar switches.

Amend the first full paragraph on page 5 to read as follows:

a11

In general, it is preferable for an adaptive optical element to maintain its full dynamic range of adaptation, while simultaneously providing acceptable control over that range, most particularly, at the low end of the adaptation range. The concern related to the low end of the adaptation range is due to the fact that there are many optical systems in which slight adaptation of focal lengths and the like, may result in greatly disproportionate effects within the overall optical systems.

Amend the second full paragraph on page 5 to read as follows:

a12

Another approach for providing adaptive optical elements involves providing a membrane that is fixed at its perimeter, or that extends over a system of holes, and then deforming one or more of these membranes using an electric field for electrostatic attraction. The typical device fabricated in this way may be used to produce beam

a12 cont

extinction or modulation by employing very tiny deformations together with the principle of optical interference. Along with these general principles of operation, comes a general tendency of these devices to be inherently wavelength-sensitive.

Delete the following text from pages 5 and 6:

--Some of the objects of the present invention include:

1. to present a method by which a wide range of adaptive optical refraction may be produced with good accuracy and reproducibility,

2. to ensure optical beam refraction with a reproducible zero-voltage state,

3. to obtain optical refraction that is both rapidly adjustable,

4. to provide a means to obtain a fixed degree of refraction when the wavelength is changed,

5. to provide a method by which the objects may be attained in a miniaturizable device,

6. to provide a method to ensure that the above objects are attained in a manner that is compatible with the requirements of micro-machined optical crossbar switches, and

7. to ensure the integration of such high-speed adaptive lenses in order to allow their

incorporation into miniaturized multi-channel optical devices.--

After the text on page 6, add the following:

a13

"FIG. 3 shows one possible embodiment for implementing an array of devices of the type shown in FIG. 1.

FIG. 4 shows another possible embodiment for implementing an array of devices of the type shown in FIG. 1."

Amend the first full paragraph on page 7 to read as follows:

a14

FIG. 1 illustrates a preferred embodiment of a micro-electromechanical (MEMS) adaptive lens in accordance with the present invention. In a practical application such as an optical crossbar switch, the complete switch may have an array of elements of the type depicted here. For the sake of clarity, FIG. 1 shows a single adaptive lens element.

Amend the second full paragraph on page 7 to read as follows:

a15

Referring now to FIG. 1, flexible transparent electrode 1 is fashioned from a transparent and conductive material on top of flexible insulating layer 2. The two layers are fashioned over a circular "pillbox" cavity in frame 3 of the MEMS device. The portions of the two layers 1,2 that are suspended over the cavity in frame 3 constitute a transparen "membrane" of the adaptive lens. Frame 3 represents a fixed member of the MEMS device depicted in FIG. 1. Frame 3 may be fashioned from silicon, poly-silicon, or a variety of other micro-machining-compatible materials, including silicon nitride.

Amend the third full paragraph on page 7 to read as follows:

a16

In the preferred embodiment of the present invention, flexible transparent electrode 1 is composed of indium tin oxide, but in the general case the material used to form flexible transparent electrode 1 (which provides a transmitting function) may be selected to suit the light being transmitted. It is also possible to add additional transparent layers to electrode 1; for example, anti-reflection layers can be added on top of transparent conductive layer 1.

Amend the second full paragraph on page 8 to read as follows:

a17

Flexible insulating transparent layer 2 is fashioned such that its peripheral edges extend over frame 3. In the preferred embodiment of the present invention, it is preferred that the elastic properties of the membrane be provided by flexible insulating transparent layer 2 in the form of a silicon nitride layer, which is optically transmissive at the wavelengths of concern, and that the electrode function of the membrane be provided by an indium tin oxide layer constituting optically transparent conductive layer 1. This choice of materials is due in part to the fact that indium tin oxide has desirable transmissive properties and is conductive, while silicon nitride is well established as a preferred material for flexible structures in MEMS devices due to its desirable elastic properties.

Amend the third full paragraph on page 8 to read as follows:

a18

The air space under flexible insulating transparent layer 2 may be created using a sacrificial layer micro-machining process. Sacrificial layer techniques are well established in the microelectronics and micro-electromechanical systems (MEMS) fields and will not be detailed herein. Transparent base electrode 6 may

a18 cont

be fashioned from a transparent conductive material, such as indium tin oxide, on top of transparent base 4 by standard deposition processes. Glass is the material of choice for transparent base 4 in the preferred embodiment of the present invention, which is directed at operating wavelengths of 1550 nm. Silicon of the appropriate purity may be employed as material from which to form transparent base 4 for wavelengths greater than the band gap of silicon. In the general case, the material used to form transparent base 4 is required to be transparent at the wavelength range of choice.

Amend the first full paragraph on page 9 to read as follows:

a19

By fashioning flexible insulating transparent layer **2** from an insulating material, such as silicon nitride, flexible insulating layer **2** ensures electrical isolation between electrode **1** and transparent base electrode **6** in those cases where the material employed for the transparent base **4** is conductive, such as will be the case for a base **4** made of silicon. The transparent membrane is therefore attached along its perimeter to the fixed member, frame **3**. It is to be noted that the perimeter referred to here is that of the transparent membrane as a whole; that is, the outer sections of layers 1 and 2 that are suspended over the "pillbox" cavity in frame **3**.

Amend the second full paragraph on page 9 to read as follows:

a20

There are many variations on the generic processes for fabricating micro-machined devices, such as the adaptive lens described in this preferred embodiment. A detailed description of a representative variant of this kind of processing of MEMS devices is given by Bifano et al in Optical Engineering, Vol 36 (5), pp. 1354-1360 (May 1977).

Amend the third full paragraph on page 9 to read as follows:

a21

Access hole 7 may be formed in frame 3 for two purposes. Firstly, it may serve as vent for trapped air when the transparent membrane of the device flexes, and secondly, it may be employed to inject a refractive liquid 5 into the space formed by the "pillbox" cavity in frame 3. In the preferred embodiment of the present invention, this refractive liquid 5 is preferably optical immersion oil. In general, the refractive liquid 5 is chosen to have a high refractive index, a low vapor pressure and as low a viscosity as possible. Optical immersion oil satisfies these requirements.

Amend the paragraph spanning pages 9 and 10 to read as follows:

a22

During fabrication, those surfaces of the device that fall inside the "pillbox" cavity of frame 3, including transparent base electrode 6, may be treated with an oleophobic material such as the low surface energy coatings employed as standard practice in MEMS fabrication to counter the well-known stiction problem. Since there is no preferential site for an injected oil droplet 5 on these oleophobic surfaces, the oil droplet 5 localizes itself in the middle of the "pillbox" cavity and fills the "pillbox" cavity to a degree determined by the droplet volume. The volume of refracted oil 5 selected in the preferred embodiment of the present invention, is such that the droplet 5 conforms with both the central portion of the transparent membrane and with the transparent base electrode 6.

Amend the first full paragraph on page 10 to read as follows:

a23

The adaptive refractive function of the present invention is established by the combination of refractive liquid droplet 5, flexible insulating transparent layer 2, flexible transparent electrode 1, transparent base

electrode 6, and transparent base 4. In this description, we refer to the combination of transparent base electrode 6 and the transparent base 4 as the "transparent flat". The refractive liquid droplet 5 therefore combines with the transparent membrane and the transparent flat to create an adaptive lens. The transparent membrane separates two refractive regions of differing refractive index. In the case of the preferred embodiment of the present invention, the two regions are air and optical immersion oil 5. In the general case, the two regions of differing refractive index can be made up of a wide selection of substances and it is generally possible to implement the present invention with any fluid on one of the two sides of the membrane. In this description, the term "refractive region" is therefore used to describe any body of material, gas, liquid, or other substance with a refractive index, specifically including free space and vacuum.

a23 cont

Amend the second full paragraph on page 10 to read as follows:

It is evident that the processes described herein may be used to create alternative detailed embodiments of the current invention that allow fabrication by planar processing in which devices are fashioned within deposited layers, rather than etching the frame 3 of FIG. 1.

a24

Amend the second full paragraph on page 11 to read as follows:

In FIG.1, light beam 10 is shown to be focused by lens 8. Application of a voltage difference between electrodes 1 and 6 causes an electrostatic attractive force between the two electrodes 6 and 1. This is a standard actuating technique employed in many MEMS devices. In the case of the preferred embodiment of the present invention, as shown in FIG.1, this electrostatic attractive force

a25

a28 cont'd

results in the transparent membrane deforming into the "pillbox" cavity of frame 3 in a substantially radially symmetrical fashion to form a concave surface. This deformation and the resultant concave surface are shown exaggerated in FIG.1 for the sake of clarity.

Amend the third full paragraph on page 11 to read as follows:

a26

This deformation causes light beam 6 to be refracted, and change focus as the adaptive lens device assumes the shape of a half-concave lens and acquires a distinct negative focal length that becomes shorter with increasing applied voltage. In the preferred embodiment of the present invention, as shown in FIG. 1, the negative focal length of the device has the effect of causing a divergence in light beam 10 in opposition to the convergent effect of fixed focal length lens 8. As the voltage is increased, the refractive divergence caused by the adaptive lens device increases.

Amend the second full paragraph on page 12 to read as follows:

a27

The purpose of this pre-stressing step is to obtain a radially symmetrical stress-field in the transparent membrane. This pre-stressing ensures that the transparent membrane is as flat as possible when no voltage is applied between electrodes 1 and 6. The flat surface of the transparent membrane in turn ensures that, at zero applied voltage, the device will transmit light beam 10 with a minimum possible change in direction.

Amend the third full paragraph on page 12 to read as follows:

a28

Minimizing the change in the propagation direction of optical beam 10 at zero applied voltage is an important requirement for adaptive lenses that are to function at the low-end of the adaptation range. The pre-stressing

a28 cont'd

also provides the device with better control over membrane displacement, particularly at low voltages and small displacements. It furthermore ensures a high natural resonance frequency, which allows the device to be employed in systems that require rapidly varying adaptation.

Amend the paragraph spanning pages 12 and 13 to read as follows:

a29

In the case of the present invention, the stressed circular transparent membrane has a distinctive and well-controllable elastic deformation. MEMS devices are well known to exhibit a so-called "snap-down" phenomenon. Snap down occurs in cantilever devices when the voltage applied to the device reaches a point at which the elastic restoring force of the cantilever is exceeded by the electrostatic attractive force and the cantilever physically snaps down onto the silicon substrate. The present invention, by virtue of the choice of circular membrane and pre-stressing, exhibits a deformation of the transparent membrane that is both radially symmetrical and much more controllable than cantilever devices. The choice of membrane materials, thickness and pre-stressing jointly determine the extent of deformation of the center of the membrane for a given applied voltage.

Amend the first full paragraph on page 13 to read as follows:

a30

The elastic deformation of the transparent membrane is substantially concave in nature with the precise shape being determined by the diameter and elastic properties of the transparent membrane, the lateral extent of electrode 6, and the magnitude of the applied voltage.

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Amend the second full paragraph on page 13 to read as follows:

a31

A pre-stressed circular transparent membrane is particularly well suited for applications requiring low degrees of refraction. In such cases, the deformation of the transparent membrane is extremely small and yet has to be controlled.

Amend the first full paragraph on page 14 to read as follows:

a32

Another object of the invention is to ensure that optimal control over the deformation is obtained, particularly at small deformations. With devices that are not pre-stressed, the transparent membrane can assume a variety of deformations under the action of the voltage and the attenuation will therefore be difficult to control. By pre-stressing the membrane, the device is effectively being biased towards a flat orientation so as to achieve maximal optical throughput and minimum refractive effect at zero applied voltage.

Amend the first full paragraph on page 15 to read as follows:

a33

In the more general case, the perimeter of the membrane need not be circular, but may be of any smoothly varying two-dimensional shape. This allows the membrane to be pre-stressed without inducing areas of excessive local stress, such as will occur at sharp corners. One particular alternative embodiment, in this respect, is a structure that is substantially rectangular with rounded corners and which will, near the center of its extent, behave as a cylindrical lens. Such elements are important for use with light sources that have differing divergence in perpendicular directions, such as side-emitting semiconductor lasers.

Amend the second full paragraph on page 15 to read as follows:

a34

The device may be adjusted according to the light source used. In particular, the voltage on the device may be changed to compensate for the variation of refractive index with the wavelength of the source, thereby keeping focal lengths the same. The wavelength limitations involved pertain only to the choice of materials. This matter is in the hands of the designer of products embodying the invention and does not limit the invention itself in respect of wavelength.

Amend the third full paragraph on page 15 to read as follows:

a35

No feedback is employed in the preferred embodiment of the present invention, as the addition of such a function adds to the complexity and cost of the device. However, feedback can be incorporated in an alternative embodiment of the present invention by a number of different means. These include capacitively measuring the membrane position or sampling the light going in and coming out and adjusting the applied voltage and consequent deformation based on this measurement.

Amend the first full paragraph on page 16 to read as follows:

a36

The actuation of the membrane may be linearized or given any desirable transfer function. The term "linearization" is used in this description to describe any collection of steps or mechanisms that leads to the behavior of the device being mathematically described by a set of linear equations. One way in which this may be achieved is by means of lookup tables relating the input actuation and output deformation of the membrane. A linearization look-up table can be included in a semiconductor memory structure, which may be incorporated on the same contiguous piece of silicon wafer as the adaptive lens itself. In a co-pending United States patent application

a36 cont'd

entitled "Method for linearization of an actuator via force gradient modification" (US serial number 09/813839) which is hereby incorporated by reference, this kind of mechanism is described in detail.

Amend the paragraph spanning pages 16 and 17 to read as follows:

a37

FIG. 2 shows a block diagram of such an alternative embodiment of the present invention in which the preferred embodiment shown in FIG. 1, is incorporated as adaptive lens 12, with impinging light beam **10**. Adaptive lens **12** can also be controlled via control signal 13 which is adapted by linearization module **17** and provided to the adaptive lens 12 as actuation signal **14**. The deformation of the membrane of adaptive lens **12** is sensed by position sensing means **15**, which provides linearization module **17** with a feedback signal **16**. Input power **18**, typically 5 VDC, 12 VDC, or 48 VDC, is provided to the whole system and power supply **19** uses this energy source to provide the linearization module 17, and thereby adaptive lens **12**, with a higher voltage **20**, which may typically be between 50 and 100 V. Linearization module **17** generates the actuation signal **14** as a voltage, typically 0-100V. The linearization module can be of the analog type or, preferably, digital with a lookup-table and programmable with an arbitrary transfer function. Such methods are well known in the art. For greater long-term stability a feedback sensor **15** measures the actual position and/or performance of the adaptive lens **12** and further modifies the actuation signal **14**.

Amend the first full paragraph on page 17 to read as follows:

a38

FIG.1 shows one adaptive lens element with an associated light source and collimating lens. This embodiment of the present invention may be repeated in two dimensions in a plane to create an array of adaptive lenses. It is

a38 cont

possible to fabricate all of these devices on a single contiguous section of silicon wafer using standard MEMS technology as described and referred to above. In this way, it is possible to generate one or two-dimensional arrays of adaptive lenses for managing optical beams from a multiplicity of optical channels. Any or all of these may be implemented with the feedback and control mechanisms shown in FIG. 2 in order to ensure adequate control over the refraction process.

Amend the second full paragraph on page 17 to read as follows:

a39

A number of different ways exist to combine these individual adaptive elements. In FIG 3 and FIG.4, two ways are shown in which such elements may be combined. For the sake of clarity, FIG. 3 and FIG. 4 show arrays of adaptive devices in only one direction, but it will be clear to those skilled in the art, that the same principles may be applied to create two-dimensional arrays. In both cases the numbering of components, for the sake of clarity, is the same as in FIG.1. In both FIG.3 and FIG. 4, use is made of a communal transparent base electrode **6**. In the case of the embodiment shown in FIG.3, each element has its own refractive liquid droplet **5** in a dedicated "pillbox" structure, similar to FIG.1. However, in the case of the embodiment shown in FIG.4, all the elements in the array share a communal droplet of refractive liquid **5**. The individual refractive lenses are formed by localized deformation of the droplet underneath a particular transparent membrane that is deformed by an applied voltage.